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# IMR ecosystem activity in the Arctic Ocean

## Report from committee

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## Table of Contents

# 1 Introduction

The Arctic Ocean is experiencing major transformations. The ongoing changes in the Arctic sea ice extent have already opened up large areas in the waters under Norwegian jurisdiction in the Arctic, enabling an increasing human presence and activity. These developments put pressures on Arctic Ocean ecosystems, and new challenges for their sustainable management arise (AC, 2004). The reduction in extent, thickness and age of the Arctic Ocean sea ice is a visible sign of climate change. The direction of change has been predicted by global models, but the speed of change has been underestimated (AC, 2011). The area in the Arctic Ocean covered by ice reached an all-time low in September 2012 (3.6 million $km^2$).

The opening up of areas that until recently have been almost inaccessible for commercial activities is a major development following the retreat of the sea ice. These changes in ocean climate and ice regime are likely to be followed by changes in the Arctic Ocean ecosystem. We have limited knowledge of the biological components and the functionality of the ecosystem in this high Arctic area. In addition, there is large uncertainty regarding current and future productivity of this ecosystem. Thus, there is a need of quantitative knowledge regarding processes and energy flow at lower trophic levels (phytoplankton/micro zooplankton, zooplankton and zoobenthos) to higher trophic levels (e.g., fish, sea mammals). It is vital also to couple this knowledge on food web structure and rates to species distribution in time and space. In addition, increased human activity including ship traffic in these “new” areas of the Arctic entails a high risk for introducing alien species from remote areas, causing bioinvasion hazards to the ecosystem. Also the exploitation of petroleum resources in the Arctic is likely to be a large activity in the near future. Moreover, the Arctic Ocean is also the most vulnerable to the effect of increased $CO_2$-levels (Orr et al., 2005; Steinacher et al., 2009), leading to so-called ocean acidification, which may be detrimental to organisms, and hence affect energy transfer through food-chains (i.e., Fabry et al., 2008). Several studies have demonstrated a coupling between sea-ice melt and calcification state, implying that further freshwater addition from glacier and sea-ice melt may speed up acidification (i.e. Chierici and Fransson, 2009; Yamamoto-Kawai, 2009). Three Fram Centre Flagship initiatives, ”Sea Ice in the Arctic Ocean, Technology and Systems of Agreements”, ”Effects of climate change on fjord and coastal ecosystems in the north” and “Ocean Acidification and Ecosystem effects in Northern Waters” partly address some related components. However, the activities proposed in this report are complementary and should be established in close cooperation with these Flagship initiatives, but should also be coordinated with other ongoing or planned national and international initiatives.

Following the United Nations Environment Programme report on Large Marine Ecosystems (PAME, 2011), we use the continental slope as the boundary between the Arctic Ocean proper and shelf seas surrounding it (Figure 1). Thus the Arctic Ocean is here defined as the deep ocean to the north of the continental slope. The waters under Norwegian jurisdiction in the Arctic Ocean are bordered to the south by the Barents Sea (Figure 1). In this view the shallow shelf north of Svalbard and in the Barents Sea are defined as the Barents Sea (and the Barents Sea Large Marine Ecosystem). We find this definition more appropriate as advice on fisheries in this region is presently provided by the International Council for the Exploration of the Sea (ICES). However, it is realized that the shelf and deep Arctic Ocean beyond, are parts of a larger Arctic region, which cannot be fully understood unless the importance of the interplay between the shelf and the deep Arctic Ocean is taken into account.

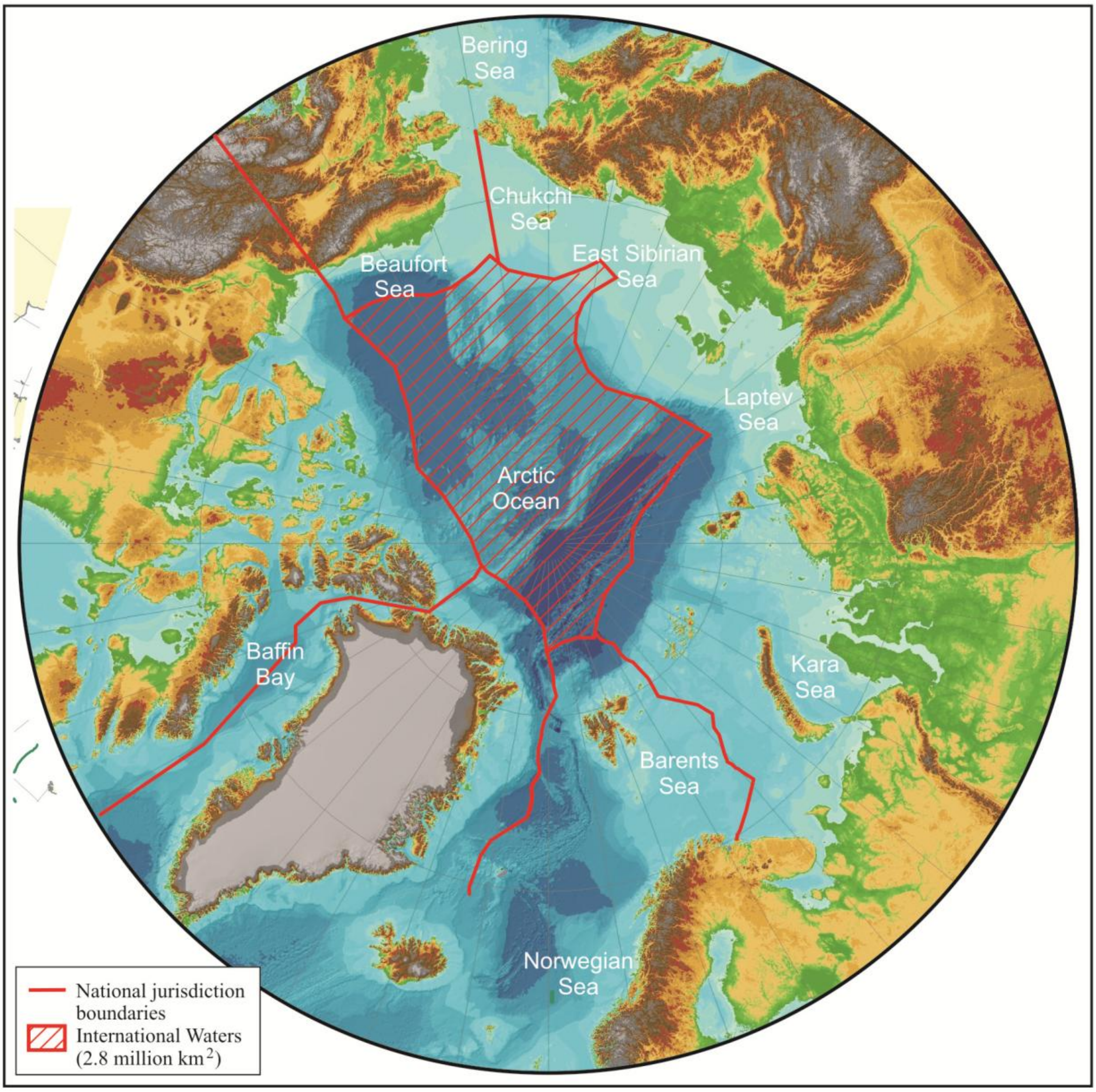


**Figure 1.** Bathymetric map showing the Arctic Ocean and the national jurisdiction boundaries.

The main focus of the report will be the ecosystem of the waters within Norwegian jurisdiction of the Arctic Ocean. However, as this ecosystem is part of the much larger Arctic Ocean ecosystem, it is also of interest to conduct investigations in the Arctic Ocean outside the region under Norwegian jurisdiction. Moreover, due to the interplay between the Arctic Ocean and the Barents Sea, focus must also be drawn to processes in the northern Barents Sea.

While the sovereign rights of coastal states over natural resources do not extend beyond 200 nautical miles in the *water,* the sovereign rights for the *ocean floor* extend further when on a continental shelf (Figure 2). Where the continental shelf extends beyond the 200 nautical mile limit, the coastal states have sovereign rights over the natural resources to the point where the continental shelf meets the deep sea floor.

The commercially most important living marine resources of the Barents Sea ecosystem are managed jointly by Norway and Russia, and today's scientific monitoring of the area is mainly a joint Norwegian (IMR) and Russian (PINRO) effort. The joint monitoring program started in the 1970s, but has been developed and strengthened during the last decades. Now, it includes a joint ecosystem survey covering all trophic levels as well as chemical and physical properties of the entire Barents Sea during autumn and a joint winter survey targeting cod and haddock in the ice-free southern parts of the Barents Sea during late winter. Both partners agree that the Barents Sea ecosystem survey area will be extended northwards to cover the distribution area of joint resources. IMR and PINRO have also conducted surveys to monitor ice dependent seal populations over several decades – a continuation of these activities will enable assessment of the effect of the retreating sea ice on these pagophilic top predators.

Marine bioprospecting is a central theme of the Norwegian Government's High North Strategy. The new areas in the Arctic will allow MARBANK to explore and search for organisms, molecules with unique properties bioactive compounds or genes in marine organisms in a systematic way, with the intent of developing products of commercial or social value.

The priorities outlined in the recent national HAV21 report states that marine research in the Arctic Ocean should be of high priority, and that existing marine infrastructure should be used and developed for collecting data, taking advantage of cooperative interdisciplinary approaches are. The IMR is a world leading institute in monitoring, research and advice for ecosystem based management at all trophic levels. Continued use and further development of the already existing vast infrastructure and interdisciplinary scientific manpower of the institute, to maintain and advance its national and international leading position in the Arctic Ocean also in the future is important and consistent with HAV21.

## 2 Possible changes in the Arctic Ocean Ecosystem due to warming

Dramatic seasonal changes, low temperatures, extensive permanent and seasonal ice cover, and a large supply of freshwater from rivers and melting ice are key physical factors characterizing the Arctic Ocean ecosystem. The oceanography of the system is influenced by vigorous flow of Atlantic Water through the Fram Strait, exchange with the shallow Barents Sea, as well as substantial cooling and mixing. Ice breakup currently occurs in June or July and re-forms in September or October. In summer, water stratifies in response to temperature and salinity, forming a vertically layered water column. Primary production is influenced by the timing of ice breakup and stratification affecting the nutrient and light availability, resulting in a short production season. This will to a large extent control the food supply to pelagic and benthic species.

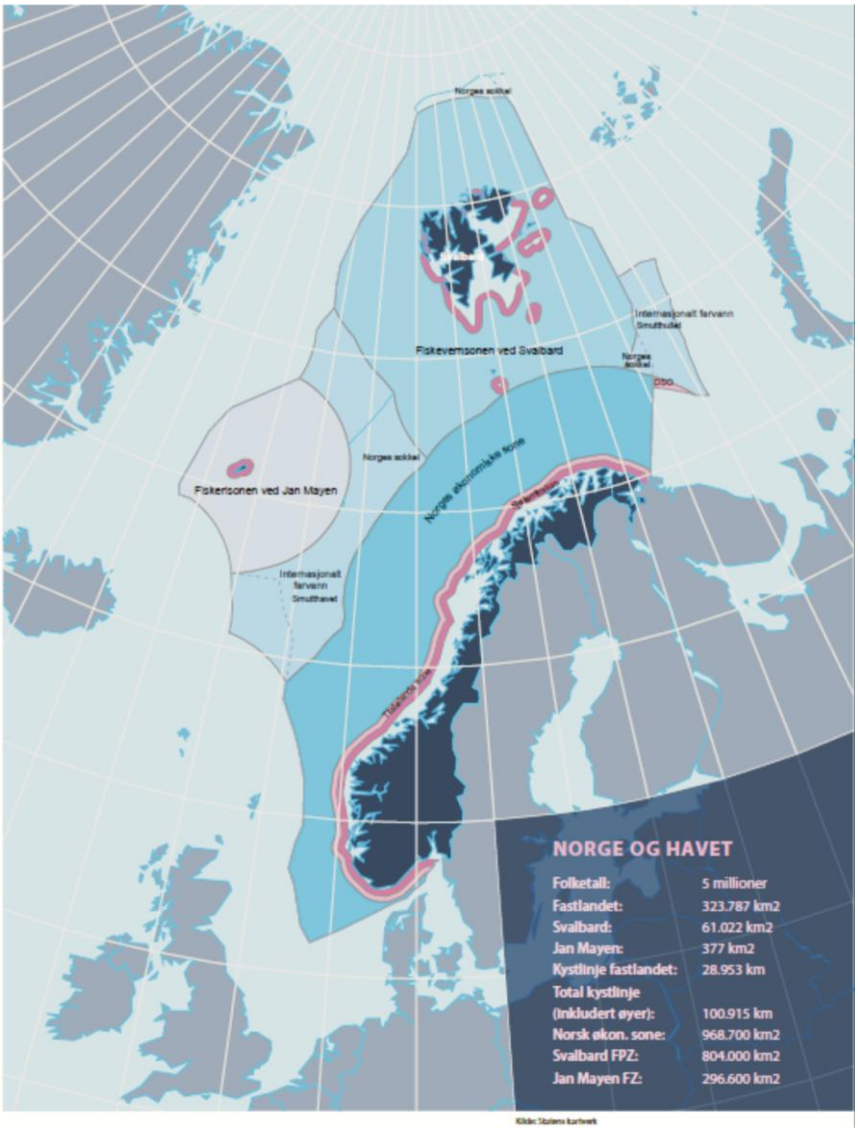


**Figure 2.** Map showing areas under Norwegian jurisdiction. The map is taken from the HAV21-report.

The past decade has seen substantial advances in understanding Arctic amplification – that trends and variability in temperature tend to be larger in the Arctic region than for the Northern Hemisphere or globe as a whole (Serreze and Barry, 2011). The Arctic amplification is associated with multiple intertwined causes and feedbacks including (but not limited to) changes in sea ice extent, atmospheric and oceanic heat transports, cloud cover and water vapour that alter the long wave radiation flux to the surface, soot on snow and heightened black carbon aerosol concentrations. Strong warming over (and in) the Arctic during the past decade, clearly associated with reduced sea ice extent, is the most recent manifestation of the phenomenon (Serreze and Barry, 2011). The Arctic amplification observed today is expected to become stronger in the coming decades, most certainly invoking further changes in atmospheric and oceanic circulation, ice extent and thickness, length of melting season, the carbon cycle and the marine and the terrestrial ecosystems, with impacts both within and beyond the Arctic.

## 2.1 Oceanography, primary and secondary production

*Atlantic inflow to the Arctic Ocean - two branches*

The flow of Atlantic Water into the Arctic Ocean takes two main routes: one across the Barents Sea shelf and the other around it. The latter branch flows as the West Spitsbergen Current along the slope through the Fram Strait and then turns east along the slope north of Svalbard. The two branches of inflowing Atlantic Water to the Arctic Ocean meet again along the northern rim of the Barents and Kara seas. The properties of these two sources of Atlantic Water are modified en route by cooling, ice formation and ice melt, and mixing. These modifications are important for the behaviour of the two branches when they meet in the northern Barents and Kara seas. The Barents Sea water has typically lower temperature and somewhat lower salinity but still higher density than the Fram Strait water and will therefore sink below the latter as an intermediate water layer in the Arctic Ocean. Thus processes in the northern Barents Sea influence the properties of the Barents Sea Atlantic Water which may have consequences for the water mass structure and circulation in the Arctic Ocean.

Studies on the modifications and interactions of the two inflowing branches of Atlantic Water, through or around the Barents Sea shelf plateau, is a research area that will be important to improve our basic understanding of both the Barents Sea and the Arctic Ocean ecosystems. It is also relevant for our understanding of the natural climate and ecosystem variability, as well as for our ability to assess and predict impacts of future climate change.

*Transport of plankton with the West Spitsbergen Current*

There has been focus on the importance of transport of plankton with Atlantic Water into the Barents Sea across the western boundary from the Norwegian Sea. There is a similar transport of plankton with the Atlantic Water of the West Spitsbergen Current into the Arctic Ocean north of Svalbard. *Calanus finmarchicus* is transported into the Arctic Ocean by this current, at least onto the Laptev shelf where it appears not to reproduce and to be expatriated (Jaschnov, 1966, 1970; Kosobokova et al., 1995, 1998). The boreal amphipod species *Themisto abyssorum* also occur in the northern Kara and Laptev seas, transported into these areas by the slope current of Atlantic Water; this species also occur in the central Arctic Ocean but in much lower densities than in the core of the Atlantic inflow north of Svalbard (Mumm et al., 1998). The krill species *Thysanoessa inermis* and *Thysanoessa longicaudata* also occur in the northern Kara and Laptev seas (Zenkevitch, 1963; Kosobokova et al., 1998).

Large individuals of *Thysanoessa longicaudata* have been observed in fairly high abundance in the northern Laptev Sea, and they also reproduce there as evidenced by the presence of eggs and larvae in the plankton.

Transport of zooplankton with the slope current along the northern Barents Sea (and further into the Kara and Laptev seas) may represent an important process for the productivity in these northern waters. The advective transport may to some extent decouple the food availability for plankton feeders and other consumers for the relatively low local primary production. The role of transport of zooplankton (and also of phytoplankton and organic matter) with the Fram Strait branch of Atlantic Water should be a priority research area. Advection from the slope onto the northern Barents Sea shelf is a part of this topic and should be clarified and quantified. As *Thysanoessa inermis* is a shelf species, the currents may potentially lead to a concentration of this krill species in sloping areas of the northern Barents shelf where they may actively avoid being transported into more shallow (and cold) waters.

*Northern extension of arctic-boreal species and their competitive potential*

Most mesozooplankters that dominate in the Arctic Ocean today are to a large extent, although with the exception of the pure Arctic species, the same as those occurring slightly further south. These types of zooplankton are being transported by Atlantic Water masses from the south trough the Fram strait into the Arctic Ocean. They are to a certain extent able to sustain populations in here, but could be vulnerable due to changes in predation pressure or to other unfavorable conditions. As the sea ice retreats there could appear new niches that allow other zooplankters (i.e. ctenophores and jellyfish medusa) to increase their abundance, maybe on the expense of traditionally abundant forms, which again could lead to shifts in the energy pathways in the Arctic Ocean, even without the influence of introduced or alien species.

In essence the northward extension of species like *Calanus finmarchicus*, and potentially opportunistic zooplankters (i.e. ctenophores and scyphomedusae) should be monitored carefully to understand responses of traditional arcto-boreal zooplankton to sea-ice retraction and any competitive advantages. Species and groups as mentioned above should deserve particular attention both with regard to monitoring and scientific advice.

*Vertical stratification and primary production in the Arctic Ocean*

There are 4 main vertical layers of water in the Arctic Ocean:

- An upper seasonally dynamic and mixed layer (in winter) (0-30/50 m)
- A halocline with strong gradients in salinity and density (ca. 50-200 m)
- Atlantic Water (with substantial heat content, can melt ice; ca. 200-1000 m)
- Deep water (ca. 1000-4000 m)

The Atlantic Water circulates as a boundary current in the Arctic Ocean basins. Both the Atlantic Water and the deep water in particular most probably offer a physical continuation of the habitats of the Norwegian and Greenland Seas. Advective transport through the Fram strait is a key physical characteristic of the innate coupling between these large ocean basins, hence of considerable ecological importance. In terms of biodiversity it is largely the same species found in these deep basins, with few species being endemic to the Arctic Ocean.

The strong and permanent stratification caused by the halocline and the seasonal strong stratification within the upper layer (caused by seasonal ice melt) result in a nutrient deficient upper layer (nitrate concentrations 2-4 µmol $l^{-1}$). Along with low light due to ice and a short growing season, this limits the growth of ice algae and phytoplankton. Annual primary production is typically 5-15 g C $m^{-2}$ $y^{-1}$ in the central Arctic Ocean, while being 20-50 g C $m^{-2}$ $y^{-1}$ in the seasonally ice covered shelf areas around the periphery of the Arctic Ocean. With less ice due to climate change, the Arctic Ocean will still remain a low productive region although the length of the productive period may become somewhat extended, with a moderate increase in the total yearly primary production. However, this could be counteracted by lower nutrient availability due to increased freshwater runoff, stronger water column stratification. Another unknown is the recurrence of passing atmospheric lows, generating strong winds that mix nutrient rich water up into the photic zone, after the main spring bloom, an effect important in the Barents Sea proper (Sakshaug, 1997).

*Zooplankton in the Arctic Ocean*

*Calanus hyperboreus* and *Metridia longa* are the two dominant larger copepods in the Arctic Ocean. They cope under the low productive regime by being large and able to survive long periods without food and to complete development with a multiannual life cycle (*Calanus hyperboreus*) or to feed as an omnivore (*Metridia*). *Calanus glacialis* is a shelf species that is far less successful over deep water in the Arctic Ocean and in the Greenland Sea. With climate change and less ice it can be expected that there will a few qualitative changes in the zooplankton community, with a possible moderate increase in growth for some species but still low overall production. There are however many uncertainties, one to be particularly aware of is the ability of grazers like ctenophores and scyphomedusae to take advantage of new habitats and resources, that could potentially change energy pathways and food-web dynamics, shifting food energy away from fish towards bacteria.

Predicting the future of the pan-Arctic ecosystem remains a challenge not only because of the ever-changing nature of both physical and biological alterations, but also because of a staggering lack of marine ecological knowledge (Wassmann, 2011). Recent progress in predicting changes in the lower trophic levels can be found in a special volume in Progress in Oceanography (Wassmann, 2011). The volume has focus on ecology of the pan-Arctic; summarizing what is known today, fundamental elements of pan-Arctic ecosystems, rapid climate change of Arctic Ocean ecosystems and outline future research needs for an integrated pan-Arctic approach. Summarizing the results from the special volume, Wassmann (2011) give (among others) the following predictions on how and when Arctic Ocean marine ecosystem will be affected by climate change and what trends can be expected:

- The largest changes will take place in the northern sections of today's seasonal ice-covered zones, which will expand to cover the entire Arctic Ocean. Primary production will increase by up to 60 g C $m^{-2}$year$^{-1}$ in what are currently low-productive basins.

- Mesozooplankton productivity will increase over the entire central Arctic Ocean, in particular along the shelf breaks, but boreal forms may not be able to penetrate into the Arctic Ocean and reproduce there.
- Due to the thinning of the ice, the significance of ice algae for the total primary production of the Arctic Ocean may increase in the central Arctic Ocean, but decrease in the outer seasonal ice-covered zones. The blooms of ice and plankton algae will stretch over longer periods of time.
- Freshening of the Arctic Ocean, nutrient limitation and a prolonged growing season will shift the community composition towards smaller phyto- and zooplankton forms.

Most of the results and predictions above have arise from current understanding and knowledge on climate forcing and impacts on the lower trophic levels (primary and secondary production). Such predictions should be additionally explored and evaluated using physical-biological coupled models. There are still large knowledge gaps considering observed abundance and biomass of the planktonic species and fish abundance and distribution, reflecting the lack of current observation programmes.

*The Arctic Ocean and the northern Barents Sea*

The Barents Sea as defined here (and the Barents Sea Large Marine Ecosystem as defined by PAME, 2011) includes the slope towards the Arctic Ocean basin. The slope current of inflowing Atlantic Water (the continuation of the West Spitsbergen Current) is an important determining factor for conditions in the northern Barents Sea.

The northern Barents Sea is (obviously) part of the Barents Sea and conditions there influence conditions further south. Arctic zooplankton (e.g. *Calanus glacialis*, *Calanus hyperboreus* and *Themisto libellula*) are transported with the currents south and west and constitute major prey for capelin and other plankton feeders in the northern Barents Sea.

Conditions and processes in the northern Barents Sea (shelf and slope) influence conditions in the Arctic Ocean, for instance through the maintenance of the halocline. Conditions and processes in the Arctic Ocean in turn influence conditions in the Barents Sea. A sufficient understanding of the mutual interactions between the Barents Sea and the Arctic Ocean is presently lacking.

A key question for the northern Barents Sea is how ocean warming will affect the habitat and spatial extent of the shelf population of *Calanus glacialis* which is a key species in the Arctic Water food web. *Calanus glacialis* dominates on the outer shelf of the Laptev Sea but there is likely not a significant transport from the Laptev Sea towards the Barents Sea. Likewise there is probably low transport of this species from the deep portions of the Arctic Ocean in north and west. It is therefore possible that there is a more or less separate population contained in the circulation system in the northern Barents and Kara seas.

*The Arctic Ocean is part of the Arctic Mediterranean Sea*

The ridge from Scotland via the Faroe Island and Iceland to Greenland separates the deep basins of the Nordic Seas and the Arctic Ocean from the rest of the North Atlantic Ocean. The sea area north of the ridge is called the Arctic Mediterranean Sea, and the circulation and oceanographic processes here have significance for the global climate.

It is a trivial fact that the Arctic Ocean is part of the Arctic Mediterranean Sea. It may be less obvious that processes and conditions in the Arctic Ocean therefore have direct influences on the ocean climate of the southern part of this Mediterranean Sea, the Nordic Sea. Studies and better understanding of the Arctic Ocean is therefore a prerequisite for better understanding of the oceanographic and ecological conditions in the core areas of our (IMR and Norway) activities, including the Norwegian and North seas.

## 2.2 Ocean acidification

The increase in atmospheric $CO_2$ and elevated oceanic uptake of atmospheric $CO_2$, with the consequence of decreased pH and carbonate ion concentrations, are expected to put stress on marine organisms, in particular calcifiers (i.e., calanus, pteropods and fish). The Arctic Ocean is due to its carbonate chemistry with relatively high $CO_2$ levels particularly vulnerable for enhanced freshening and loss of sea-ice cover, which will promote further solubility and amplification of ocean acidification. In addition to direct effects of changes in pH and carbonate ion concentrations on marine organisms and ecosystems, there are also indirect links, affecting the processes inside the organisms on a molecular level (blood-regulatory, and protein synthesis) and through changes in biogeochemical cycling of substances, especially nutrients and micronutrients, and their bioavailability for primary production (e.g., Breibarth et al., 2010). Changes in the Arctic Ocean are already observed, and presence of aragonite-undersaturated waters on the freshwater-influenced shelves of the western Arctic Ocean in summer 2005 has been reported (Chierici and Fransson, 2009). This is substantially sooner than predicted by recent dynamic models at 2030 (Orr et al., 2005; Steinacher et al., 2009).

Data on the natural variability of pH and calcium carbonate saturation state ($\Omega$), and information on the actual $\Omega$ required for organisms to calcify, are required. Except for increased freshwater content in the Arctic, studies show that the effect of warming, possibly due to increased inflow of Atlantic Water, may affect the stability of gas hydrates on shallow shelves and bottoms. It is a great risk that a warming of the bottoms may result in a release of methane ($CH_4$), which oxidizes to $CO_2$. In addition to changes in the oxidative state (decreased oxygen levels) the increased $CO_2$ (low pH) and increased methane release will amplify ocean acidification (Biastoch et al., 2011).

Given the potential ecological consequences, studies of processes affecting the natural variability of the calcium-carbonate saturation levels in the Arctic Ocean are of great importance in predicting the impact of increased atmospheric $CO_2$ levels on the vulnerable ecosystem and carbon flow in the Arctic Ocean. Currently, there are large data gaps regarding the processes affecting the current state of ocean acidification. The urgency of investigating ocean acidification in the Arctic has initiated several international and nationwide research programs (USA, UK, Germany, and Norway).

### 2.3 Fish

Being poikilothermic animals, fish exhibit specific temperature preferences, but which environmental temperatures are preferred varies widely among species. Fish are generally classified as belonging to zoogeographic groups depending on their preferred temperature range, and the fish living in the Barents Sea and in the Arctic Ocean are either considered *Arctic*, *Arcto-boreal*, or *Boreal* species. In a warming ocean, the borders between these zoogeographic regions are being shifted towards the poles, and the fish belonging to each category is generally considered to move in a poleward direction. However, such migrations initiated by higher temperatures are complicated features, taking place at various geographic and temporal scales. It is believed that an extension of a feeding migration towards the north might occur quite rapidly, as has been observed for several species recently. A shift in spawning areas and the general migration pattern between spawning areas, feeding areas and wintering areas are much more resistant to changes, and effects will only be expected after several years of persistent temperature changes.

Considering the possible movement of fish into the Arctic Ocean, one therefore has to discern among various types of migrations. For instance, if feeding conditions improves in the Arctic Ocean because of increased primary and secondary production, one would anticipate that the present northward feeding migrations common to fish in the Barents Sea can be extended into the Arctic Ocean. However, permanent residence there is hardly thinkable at the short and medium term, constrained by the distance to the southern spawning areas and by the winter conditions in the north. If a persistent and significant rise in temperatures would force species to give up their present spawning areas and general migration pattern, their continued existence would depend on whether they can establish new spawning areas further north and establish new nursery areas, feeding areas and wintering areas in the Arctic Ocean. This would again depend on a range of other factors, a.o. topographic and hydrographical features, water mass dynamics like water column stratification and ocean currents. Similarly, whether the change implies an expansion of the distribution area or a movement into a new distribution area would depend not only on preferred temperature range but also on tolerance to un-preferred temperatures.

This discrimination between an expansion and a real shift in distribution area is also essential for a possible shift in fishing areas. Disregarding any legal measures, a fisherman will not automatically go fishing in the Arctic Ocean if the same resource is still available further south and nearer the home port (Figure 3), since the sailing is costly and would have to be counteracted by other advantages by going there, like for instance higher concentrations, more preferable fish size etc.

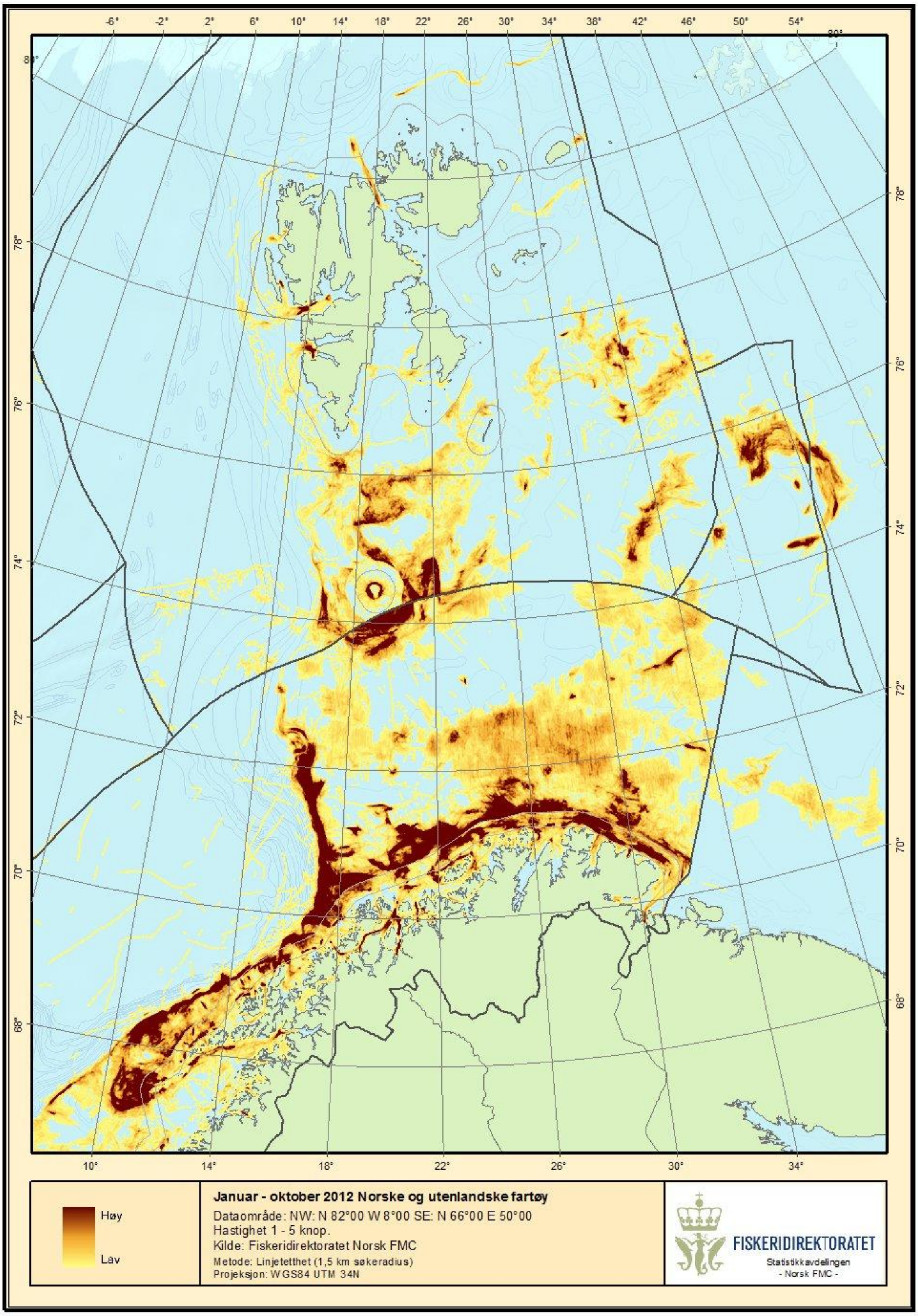


**Figure 3**. Fishing activity in Norwegian and International waters in the Barents Sea and Arctic Ocean during January-October 2012.

Below, we have compiled a table where we show how some commercial species found in the Barents Sea/Norwegian Seas today are likely to act in case of a warming Arctic. The temperature preferences are poorly known for some of these species and these must be considered indicative until more thorough investigations can be carried out.

**Table 1.** How some commercial species found in the Barents Sea/Norwegian Seas today are likely to act in case of a warming Arctic. JRNFC: Joint Russian-Norwegian Fisheries Commission. NEAFC: Northeast Atlantic Fisheries Commission. IWC: International Whaling Commission. *: Herring and blue whiting are at present only found in the Barents Sea as juvenile and are not fished there.

| Species | Demersal/ Pelagic | Temperature preferences (°C) | Likelihood of moving into the Arctic Ocean | How far? | Managed by |
|---|---|---|---|---|---|
| Cod | Demersal | >0 | Moderate | To shelf edge | JRNFC |
| Haddock | Demersal | >2 | Moderate | To shelf edge | JRNFC |
| Redfish (*S. mentella*) | Demersal/ deep water | >2 | Moderate | Unlimited | JRNFC/NEAFC |
| Greenland halibut | Demersal/ Deep water | >0 | High | Beyond shelf edge | JRNFC |
| Prawn | Demersal | >0 | High | To shelf edge | JRNFC |
| Capelin | Pelagic | >0 | Moderate | Unlimited | JRNFC |
| Polar cod | Pelagic | >-1 | High | Unlimited | JRNFC (currently Russia) |
| Herring* | Pelagic | >1 | Moderate | Unlimited | Five coastal states |
| Blue whiting* | Pelagic | >3 | Low | Unlimited | Five coastal states |
| Minke whale | Pelagic | >1 | High | Unlimited | IWC/Norway |
| Harp seal | Pelagic | >0 | High | Unlimited | JRNFC |

## 2.4 Marine mammals

Arctic marine mammals are large, highly mobile, warm blooded animals that cope well with significant amounts of variation in their environments, and they have physiological capacities that are unlikely to be challenged directly by climate changes. But, predicted reductions in sea ice are likely to have direct impacts by reducing or eliminating the current breeding habitat of many Arctic pinnipeds and shifting the location and timing of productivity in Arctic shelf seas (Kovacs & Lydersen, 2008; Kovacs et al., 2011). Further, it has been surmised that sea ice also provides protection for Arctic cetaceans from predators – increased presence of e.g. killer whales could have significant impacts on endemic Arctic whales (and seals) in an Arctic with less sea ice. Changes in ocean circulation patterns could cause shifts in the locations of fronts and the overall productivity of whole regions. These large scale changes are likely to have impacts on the distribution and abundance of marine mammals that often forage at ocean fronts and other areas where upwelling stimulates high productivity.

Expected reductions in sea ice are directly reducing the habitat available for ice-associated marine mammals that give birth on sea ice, hide from predators or inclement weather within ice fields or that eat ice-associated fish and invertebrate prey or other ice-associated marine mammals. Loss of sea ice is already affecting some species, and in the longer term, it is expected that foraging success, fertility rates, mortality rates, etc. will be impacted for additional populations and species of endemic Arctic marine mammals (see Kovacs et al., 2011). Generally speaking, specialist feeders are likely to be more heavily impacted by changes in Arctic food webs that will accompany sea-ice losses compared with generalist feeders, and ice-breeders that require long periods of stable ice late in the spring season are likely to be impacted more rapidly than late winter ice breeders that require ice for shorter periods of time (Kovacs & Lydersen, 2008).

Several seal species in the Northeast Atlantic are pagophilic (= ice-loving). During both the breeding and moulting periods, they need to haul out on ice. Both harp and hooded seals congregate in large concentrations within relatively predictable, limited areas on the drift ice during the breeding period each spring (March–April). In our waters, there are two breeding and moulting areas for the harp seal: the Greenland Sea between Jan Mayen and Greenland, often called the West Ice, and the White Sea and the southeastern Barents Sea, also called the East Ice. The hooded seal only breeds and moults in the West Ice. Outside of the breeding and moulting periods, both the harp and hooded seals are out on long feeding migrations: the harp seal primarily in the vicinity of drift ice in the Barents Sea, while hooded seals migrate to more temperate areas in the Norwegian Sea. During this period, they regularly return to the drift ice, which is then used as a place of rest.

Since they are hunted, both harp and hooded seals are monitored in that the size of their population and ability to reproduce are being measured at regular intervals (about every five years, see ICES, 2011). This has provided important insight into both the status and development of the populations. Recent observations may signal that climate change and reduction in ice cover has literally brought these two seal species on thin ice. The ice sheet in the West Ice is considerably reduced over the past 20–30 years, and the ice in the White Sea now freezes considerably later in the winter than only 5–10 years ago, and the ice is generally much thinner than before. Such changes undoubtedly represent deterioration in the vital breeding and moulting habitat for the harp and hooded seals. Mass mortality among harp seal pups has been observed in individual years with difficult ice conditions. The reduction in the ice sheet could also make seal pups more vulnerable to predation from, for example, the polar bear (because the ice sheet will become smaller and the breeding areas will be forced closer to land) and killer whales (because there will be more open water between the ice floes). The odd years where few pups survive and with low recruitment to their populations is probably something that both the harp and hooded seals are in a position to cope with. With the more permanent reduction in ice caused by climate change, this lack of new recruits could become the rule rather than the exception.

In addition to sea ice loss, combinations of other climate induced changes are likely to have indirect effects on marine mammals, mediated through impacts on their prey. Arctic marine mammals depend on rapid accumulation of energy to restore blubber stores during the short season of productivity at high latitudes (Kovacs et al., 2009). This is their main source of energy during winter and spring when their food intake is reduced. For adult females, the layer of blubber also forms the actual basis for milk production during the intensive suckling period. From mammals at the top, via their prey (large crustaceans living on plankton, capelin and polar cod) and down to the smallest crustaceans living on plankton in the Arctic food chain, it is vital that all species have a well-developed ability to absorb and store energy reserves during summer. With increasing sea temperatures, these species will come into competition with other species from more temperate areas further south where this strategy for energy storage is not really required or well-developed. This could mean a transition from high-fat to low-fat food. Initially, this could affect their ability to deposit the necessary fat resources in their blubber and, in the next stage, could affect their ability to produce viable offspring.

Northward range expansions have limited geographic scope for endemic Arctic marine mammals, leaving them vulnerable to the effects climate change produced within their current ranges. In contrast, more temperate marine mammal species are showing northward expansions of their ranges, which are likely to cause competitive pressure on some endemic Arctic species, as well as putting them at greater risk of predation, disease and parasite infections. Compression of the range of endemic, ice-associated species, as well as the competition from temperate species (e.g., baleen whales) moving north are likely to result in increased competition for food. Food resources are also likely to be more dispersed both spatially and temporally in the future compared with the situation that has existed for a long time in the Arctic with extensive polynyas and a marginal ice zone, which have both been temporally/spatially predictable (see Kovacs et al., 2011).

Physical changes in the Arctic marine environment are also likely to enact further change via alterations to human activity patterns. Ice-free expanses in the Arctic will encourage increased shipping and development that are likely to affect the abundance and distribution patterns of some species within the Arctic marine mammal community and increase the risk of anthropogenic interactions. These effects will be additive to the habitat reductions via changes to the sea ice; changes to the forage base, with less lipid-rich species dominating the community; increased competition from temperate species expansions northward; increased predation rates from killer whales and perhaps also Greenland sharks and increased disease and parasite risks.

## 2.5 Benthos

A future shift from an ice-influenced area with tight pelagic-benthic coupling to an ice-free system can be expected. A change from Arctic to subarctic conditions in the northern Bering Sea has been associated with a northward shift of the pelagic-dominated marine ecosystem that was previously limited to the south-eastern Bering Sea (Grebmeier et al., 2006). Similar ecosystem changes are likely to occur in the Barents Sea in the event of continued warming (Carroll and Carroll, 2003). Generally, water column productivity is inversely related to ice cover (reviewed in Wassmann et al., 2006), and the benthic fauna, which is an integral component of the food web, exhibits a strong association with the overlying primary productivity regime (Tremblay et al., 2011). Close benthic-pelagic relationships in ice-influenced areas have been observed in the Northeast Water Polynya off Greenland, the

Beaufort Sea and the northern Bering and Chukchi Seas as well as the Barents Sea. A significant portion of the energy in Arctic continental shelf communities may pass through the epibenthos (Piepenburg et al., 1995; Piepenburg and Schmid, 1996).

In particular, the often dominant echinoderms on Arctic shelves are highly mobile and play an important role in the redistribution and remineralisation of the organic carbon reaching the seabed (Blicher and Sejr, 2011). These organisms contribute significantly to the overall benthic biomass of the Arctic shelves despite their patchy occurrence. The importance of the mega-faunal communities in the Arctic has been acknowledged in the Chukchi Sea (Bluhm et al., 2009), the north-east Atlantic (Billett et al., 2001), East Greenland (Mayer and Piepenburg, 1996), and the Arctic deep-sea Canadian Basin (MacConald et al., 2010).

A possible effect of increased bottom fishing along the slope as a consequence of less ice, could be a reduction of habitat complexity (architecture) through the removal of sessile megabenthic species. The loss of such complexity appears to have important consequences for fish communities (e.g., Sainsbury et al., 1997).

## 2.6 Slope communities

The basins and slopes of the Norwegian and Greenland seas and the Arctic Ocean are continuous habitats with only minor differences in key physical characteristics. Atlantic Water flows along the upper slope down to a depth of 800-1000 m in the Nordic Seas as well as in the Arctic Ocean, although the water becomes colder as it flows north. The cold deep-water below that fills the basins is also very similar between the basins of the Nordic Seas and the Arctic Ocean. Both the Atlantic and deep waters are in open communication through the deep Fram Strait.

The slope and basin communities of benthos and fish in the Nordic Seas and in the Arctic Ocean are (or must be expected to be) similar in broad terms. The productivity is generally lower in the Arctic Ocean and the communities there are more impoverished compared to for instance the Norwegian Sea. There are also boreal species with ranges that extend into the Nordic Seas but not further into the Arctic Ocean. There are therefore differences in species composition and richness, with higher abundance and more species along the slope of the Norwegian Sea compared to the Arctic Ocean. However, many or most of the species found in the Arctic Ocean are arctic-boreal species which are also found in the Norwegian Sea.

# 3 Ecosystem research in the Arctic Ocean

The exploration and mapping performed in the waters under Norwegian jurisdiction in the Arctic Ocean has till recently mainly focused on the oceanic circulation patterns, the physical and chemical properties, the sea ice cover and the associated ice fauna. There are still large knowledge gaps concerning the presence, abundance and distribution of planktonic organisms, fish species, marine mammals and benthic organisms and very little is known about the production capacity at the species level, hence also in an ecosystem and changing climate context (Anon., 2011).

Key knowledge gaps with respect to the Arctic Ocean ecosystem was identified at a workshop for scientific experts from the five Arctic Coastal States in Anchorage in June 2011 (Anon., 2011). The report from the meeting states: "…it is critical that the scientific community develops a sufficient understanding of the biophysical processes governing the region to assess the ecosystem impacts of climate change, and to consider the implications of anthropogenic stress resulting from human use of natural resources under a changing climate. Further research is required to improve understanding of: the processes determining the variability in the ocean circulation, positions of oceanic fronts, species sensitivity to climate change, match/mismatch between predators and prey, indirect and non-linear effect on biological processes, and competitive interactions which may occur if new species are introduced into the ecosystem. For example, many Arctic species have relatively narrow habitat and niche requirements. Their likely response to increased competition from more opportunistic species in a warmer Arctic is unclear."

## 3.1 Exploration and mapping

Baseline information regarding physical, chemical and biological conditions are lacking for many parts of the Arctic (Anon., 2011). An exploratory study on which species are present in the waters under Norwegian jurisdiction of the Arctic Ocean, and their distribution, are thus urgently needed. Such information can mainly be achieved through field observations, but also through review of historical data and literature. The data obtained will provide a necessary baseline to further analyses, process studies and numerical modelling. Observational data can be obtained by expanding already ongoing surveys, establishing new surveys, but also utilizing data from satellites and other auxiliary sources. A research platform with the ability to go into the ice is needed and should be rented until the planned Norwegian research vessel that will be able to operate in multiyear ice is operational (by 2015).

The main focus should be on obtaining an ecosystem description and understanding of the Arctic Ocean, and key questions addressed in the baseline study should include:

- What are the main physical/chemical oceanographic properties of the Arctic Ocean today? What is the current status with respect to ocean acidification?
- What are the biomass and distribution of primary and secondary producers?
- Which fish species (pelagic and demersal), benthic species, phytoplankton and zooplankton organisms, marine mammals and sea birds are the key players in the Arctic Ocean today?

- Which of the current Arctic Ocean communities of pelagic and demersal species are a continuation of more southerly distributions of the Barents and Norwegian Seas, and which species represent separate Arctic Ocean communities?

### 3.2 Functioning of the present Arctic Ocean ecosystem

Questions regarding the extent to which climate change may impact primary productivity and whether any such changes might result in restructuring of the Arctic marine ecosystems are identified knowledge gaps for the Arctic Ocean (Anon., 2011). To answer these questions, numerical modelling must be undertaken to explore particular hypotheses or assumptions, while process studies are essential to estimate vital rates and parameters that are important for the structure and functioning of the present Arctic Ocean ecosystem. The main focus should be on the Arctic Ocean, but the interplay between the Arctic Ocean and the shallow shelf should also be incorporated.

Key questions addressed should include:

- What are the dominant processes regulating the inflow of Atlantic Water and its impact on the Arctic Ocean heat content, vertical stratification and ice cover?
- What are the dominant processes regulating exchange of water and drifting organisms (e.g., phytoplankton and zooplankton) between the northern Barents Sea and the Arctic Ocean?
- How does changes in water mass distribution and freshwater affect the ocean acidification state?
- Does changes in sea-ice cover affect uptake of $CO_2$ and ocean acidification state?
- What are the timing, growth and succession in key phytoplankton species?
- To which extent are the phytoplankton blooms and their associated biomass subject to loss through sedimentation?
- What are the response of key zooplankton species to the magnitude and quality of available food?
- How does the key zooplankton species relate to the presence of important invertebrate, fish and marine mammal predators?
- How does the benthic prey species relate to the presence of predatory invertebrates, fish and marine mammals?
- What are the dominant processes regulating spawning/birth and migration for fish and seals?

### 3.3 The Arctic Ocean Ecosystem in the future

Evidence of how climate change has resulted in clearly discernible (and observable) changes in marine Arctic ecosystems was reviewed by Wassmann et al. (2011). Most reports concerned marine mammals, particularly polar bear, and benthos, and the observed responses were dominated by reports of changes in abundance and demography. The number of well-documented changes in planktonic and benthic systems was surprisingly low. Their main conclusion was that despite the alarming nature of warming and its strong potential effects in the Arctic Ocean the current research effort evaluating the impacts of climate change in this region is very limited. Thus questions regarding the extent to which climate change may impact primary productivity and whether any such changes might result in restructuring of the Arctic marine ecosystem are still to be answered (Anon., 2011). Emphasis should be put on exploring particular hypotheses or assumptions that are crucial for the functioning of the future Arctic Ocean Ecosystem.

Key questions addressed should include:

- How will the future changes in Atlantic inflow, ice cover and ocean acidification affect the Arctic Ocean ecosystem?
- How will the future changes in ocean acidification affect key phytoplankton and zooplankton species e.g., Calanus, pteropods and krill at different life stages?
- Which conditions are necessary for organisms that presently are confined to the Barents or Norwegian Sea, to expand their distribution area northwards and establish in the Arctic Ocean? Of particular interest would be plankton species like *Calanus finmarchicus* and pelagic fish species like polar cod, capelin and herring. Can these and other species expand their distribution into the Arctic and still spawn in the same areas as before, or are there more northern areas that will be suitable for spawning?
- What are possible prey-predator links between the Arctic Ocean seabed and possible future fish resources?
- What impact would a possible increased migration of foraging whales have on the existing arctic resources?
- What would the effect of further ice reduction be on populations of pagophilic species?
- What are the potential propagule pressure for introducing alien species to the Arctic Ocean, and which species poses the highest threat?
- What would happen to Arctic grazers (fish, seals, whales, birds) if their traditional lipid rich prey species are replaced by more boreal and lipid-poor species (“junk food”)?

# 4 Ecosystem management advice

*Harvesting in the Arctic Sea – Format of advice from IMR*

The mandate given to the committee seems only to be within the realm of advice from the IMR regarding harvesting in the Arctic Ocean. However, the committee is of the opinion that advice issues from the IMR will have a much broader perspective. Therefore the committee has extended the mandate to include a range of issues of advice from IMR regarding the Arctic Ocean, not only harvesting issues.

## 4.1 Advices given at present

The scientific advice for the management of living marine resources in the Northeast Atlantic, the Nordic seas and the Barents Sea is provided by ICES in the case of most commercial species, and by the Scientific Committees of the North Atlantic Marine Mammals Commission (NAMMCO) and the International Whaling Commission (IWC). These advices are formulated on the basis of scientific monitoring and research in ICES member countries. Recipients of the advice are the ICES member countries and regional organizations. ICES advice generally covers the entire geographic extent of the waters under the jurisdiction of its member states, as well as the high seas in the Northeast Atlantic. The Joint Russian-Norwegian Fisheries Commission (JRNFC) sent in 2009 a request to ICES regarding the possibility of conducting continuous monitoring of the migratory pattern in the Arctic Ocean fish stocks (referred to above) managed by the Commission, as well as future monitoring and research on the stocks, by anchoring the matter in the mandate of an existing or in the establishment of a new Working Group. In 2011 ICES responded that ICES advises that the geographic distribution of these stocks is monitored in the ice-free parts of the Arctic Ocean once a year, using existing survey methodology. This could be coordinated by existing ICES expert groups.

Also other international programs have activities relevant to management advice. Several Arctic Council[1] working groups address questions relating to biodiversity in the Arctic and the status of its marine environment. Under the working group Conservation of Arctic Flora and Fauna (CAFF), several projects address the status of biodiversity in the Arctic, including the Circumpolar Biodiversity Monitoring Programme (CBMP) and the Arctic Biodiversity Assessment. In the working group on the Protection of the Arctic Marine Environment (PAME), several projects are relevant to the management of the Arctic marine environment; among them the Ecosystem Approach project. Also, the working group Arctic Monitoring and Assessment Programme (AMAP) does advice relevant work in assessing effects of pollution, ocean acidification and climate change on the Arctic marine environment. These working groups are not scientific working groups with advisory capacities in the sense that ICES working groups have. They are composed of administrators as well as scientists, and do not formulate scientific advice as such to the Arctic Council member states.

[1] In the Arctic Council, the Arctic is conceived of as encompassing also the Norwegian Sea as far south as the Faroe Islands.

*Integrated management plans*

In Norway, the last decade has seen the development of integrated management plans for the Barents, Norwegian and North Sea. The purpose of these plans is to facilitate value creation while at the same time ensuring that the cumulative impacts of activities does not exceed the carrying capacity of the marine environment. Ideally, all activities and pressures in the area should be managed within a single context, with aim to prevent that the total environmental pressure from activities should threaten the structure, functioning and productivity of the ecosystems. Monitoring of environmental toxins, fish resources, and impact on benthic communities, are considered together with the need for continuously increasing the general ecosystem knowledge base.

*Cooperation with Russia*

A large part of the HI-PINRO cooperation is based on the joint ecosystem survey in August-September and it is a common agreement that this survey will be extended northwards to the extent that the species of interest are moving and the waters may be surveyed. This commitment is also stated in the report from the JRNFC.

The cooperation with Russia concerning the environmental status of the Barents Sea is framed by the JRNFC. Under this commission there is a separate group for ocean environment, and the mandate for this group is to define projects to be conducted on a mutual basis. The last meeting in the Russian Norwegian environmental commission was held in 2012 at Svanhovd and this was the $20^{th}$ meeting in the commission. A new three year research program was approved. An important development in the common projects is the focus on preparing a mutual foundation for development of Russian management plans, or management regimes. The Norwegian geographical area of the management plan extends into the Arctic Sea and it is expected that the Russian area would have a similar distribution.

## 4.2 Management advice in the future

Management advice should build on scientific knowledge. At present this knowledge is insufficient to make firm conclusions about which type of management advice IMR will meet in the future. Thus addressing the knowledge gaps identified earlier in the report, as well as establishing a well-defined monitoring program, operative on all trophic levels and in a changing climate, are important recommendations also for the management advice part.

Most results so far imply that although the productivity of the Arctic Ocean will increase when larger areas become ice free, the productivity is expected to remain low (Wassmann et al., 2011) and thus insufficient to sustain large fish communities. This, in combination with uncertainties in the ecosystem effects of fishing, and the technological and logistical challenges of conducting fishing operations in remote regions, all suggest that commercial fisheries are not likely to emerge in the Arctic in the short term (5-10 yr) (Anon., 2011). Changes in long term (20-40 yr) perspectives are more uncertain. Thus it is important to establish and maintain a monitoring program suitable for early detection of changes in the Arctic Ocean ecosystem.

The centrepiece of the international, legal framework for the management of living marine resources is the 1982 Law of the Sea Convention. Fundamentally, the Convention requires coastal states to ensure 1) that living marine resources are not overexploited and 2) that resources are utilized in an optimal manner. The conservation requirement specifies that states, on the basis of the best available scientific evidence, shall establish management measures that aim at bringing populations to a level where they produce the maximum sustainable yield (MSY).

The 1995 UN Fish Stocks agreement adds the precautionary approach (= operationalization of the precautionary principle) to the set of legally binding principles for the management of living marine resources. The key issue here is the establishment of reference points for conservation (limit reference points) and utilization (target reference points). This is the foundation for the development of harvesting control rules over the last 10+ years.

In addition, there are a number of non-legally binding principles for the management of living marine resources, including the following:

- Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem (2001)
- FAO guidelines for the ecosystem approach to fisheries (2003)
- FAO guidelines for deep-water fisheries (2009)
- Johannesburg Plan of Implementation (2002) - (MSY, ecosystem-based management)
- Rio de Janeiro The future we want (2012) - (MSY, ecosystem-based management )

In a wider, ecosystem context, a number of other principles are also relevant. Under the regional cooperation for the management of the marine environment in the North Atlantic (OSPAR), for example, the ambition of ecosystem-based management is addressed by means of a series of Ecological Quality Objectives (EcoQOs) describing desired status for specific ecosystem components. In the shipping sector, a number of agreements under the International Maritime Organization (IMO) specify operational and design requirements to vessels. As regards petroleum activity, management principles fundamentally flow from the 1982 Convention, which specify ownership rights and environment-related objectives at a very general level. More specific provisions pertaining to petroleum activity are partly found in regional agreements (for example OSPAR) and in domestic legislation.

*New issues where management advice can be requested*

The committee has identified the issues given below as most relevant and most likely to be requested in the future.

*Vulnerable areas*

Management plans are a central tool in managing activities in the marine ecosystems. In the concept of management plans, identifying vulnerable areas toward anthropogenic pressures such as fishing impact, oil industry, garbage, and introduced species, are an important task. Identification of such areas is based on knowledge of both the ecosystem and the abiotic elements supporting the ecosystem. It is recommended that advice should be given on potentially vulnerable areas based on dedicated monitoring in the Arctic Ocean. Areas and methods used in such monitoring should be decided upon based on the knowledge collected in the Barents Sea and other areas.

*Petroleum*

Exploring petroleum resources in the Arctic Ocean will probably be a large activity in the short term, although the actual exploitation may be further into the future. With respect to identification of vulnerable areas, advice on the progress of exploring these resources should be developed and given. Special concern should be given to the lack of relevant knowledge in this area, and the experience learned in the Barents Sea should be used actively.

*Shipping*

With the prospects of ice free passage through several ship lanes in the Arctic Ocean and along the continental shelf's, it will be particularly important to monitor any pollution and other impact from such activity. It would be expected to have considerable risk for accidents with serious spill of oil and cargo that is being transported along these routes. Also, reloading and port visits in Svalbard or other northern areas could pose some impact to the environment. Ships in tourist business could also increase the number of ship sailing days in the Arctic Ocean and be a threat to a vulnerable environment. Advice should be developed as to the amount of vessel sailing days allowed in this area, and the type of vessels allowed, with respect to hull construction and propulsion technology.

*Environment and climate change*

IMR should focus on giving scientific advices on parameters affecting the ecosystem. This includes changes in ice cover and ocean temperatures, ocean acidification, and pollution. The advices should be given to the different groups in Arctic Council.

*Ice-associated species*

Expected reductions in sea ice are directly reducing the habitat available for ice-associated species living on or between the ice floes (e.g., marine mammals) or within/underneath (cryopelagic fauna) the floes. The loss of ice associated production may affect the entire production in the Arctic, and IMR should focus on giving an answer to this question.

Polar cod eggs, larvae and juveniles are often associated with ice – how loss of ice will affect the polar cod – a key species in the Arctic is not known. Advice will probably be requested.

Loss of sea ice represents a reduction in available habitat for ice-associated species of marine mammals that is already affecting some species, and in the longer term, it is expected that foraging success, fertility rates, mortality rates, etc. will be impacted for additional populations and species of endemic Arctic marine mammals. Also, predation (e.g., from killer whales and sharks) may increase in species otherwise protected by the ice. Ecological effects of this will be questioned.

Several seal species in the Northeast Atlantic are pagophilic (= ice-loving). During both the breeding and moulting periods, they need to haul out on ice. Both harp and hooded seals congregate in large concentrations within relatively predictable, limited areas on the drift ice during the breeding period each spring (March–April). For this reason, both species have been important for commercial sealing. Particularly the fate of harp seals, one of the most important top predators in our areas, will be questioned in a changing Arctic.

*Northward expansions or shifts*

In the future species can expand their distribution area or move into the Arctic Ocean as outlined for commercial species in section 2 (Table 1). Advice on management of fish, shellfish, seal and whale stocks in the Barents Sea and Norwegian Sea is at present provided by ICES, NAMMCO and IWC. Thus if expansion occurs, advice can still be provided through the abovementioned advisory bodies as the management areas also cover the waters within Norwegian jurisdiction of the Arctic Ocean. In addition to focus on management advice on the commercial stocks, IMR should focus on giving advice on expected status and changes in the ecosystem by including non-commercial species of fish, shellfish and marine mammals. It should be noted that a Calanus management plan is currently being developed as a precautionary instrument to assess the stocks and quantify ecological consequences of harvesting. Hence, IMR could develop similar regional plans and advices on expected status and changes in primary and secondary production, species composition, predator/prey interactions and competition.

*Fish stocks*

The ”management principle” is an important element of the Ocean Resources act. The intention in this principle is that the management authorities shall monitor the development of all stocks (fish, invertebrates etc) relevant to the different human activities (fisheries, bycatches, discards, bioprospecting, impact of gear use, ballast water etc) in the ecosystem, and if necessary, introduce relevant management measures. As the above is a considerable task, a system of prioritizing research and management measures for the various stocks has been developed by the Directorate of Fisheries and IMR (“Bestandstabellen”). IMR should focus on identifying stocks in the Arctic to be included on the priority list. The “management principle” will thus lead to a more complete ecosystem management of the area.

*Effect of fisheries on bottom fauna*

If the fisheries expand northwards and into areas where fishing has not previously been carried out, IMR should provide advice on format of reporting catches and by-catches, relevant fishing gear, and area restrictions regarding fishing operations.

*Integrated assessment*

Ecosystem approach to management (EAM) with integrated assessment (IA) is an approach to a holistic advisory system where the functioning of the ecosystem is taken into consideration. IA should be developed on top of the monitoring and ordinary stock assessments conducted by the institute. An integrated assessment is an assessment of the status and trends in all relevant ecosystem components and thereby of the overall state of the ecosystem as such. An IA is a process of work needed to support the EAM and the advices given under this concept. However, there is at present no linkage between work on EAM/IA and the present management system, and the way forward to create such a linkage is not clear-cut.

### 4.3 How to organize the management and advice

Advice from IMR will come in addition to advice given by various international organisations and bodies where IMR are involved (section 4.1). In the Arctic there is a multitude of management agencies and processes that potentially could be receivers of advice from IMR. This includes, *inter alia,* the Arctic Council, the joint Russian–Norwegian Fisheries Commission, the Russian-Norwegian Environmental Commission, various Norwegian Ministries and the Integrated Management Plan for the Barents Sea. IMR has the ability to produce a wide range of advice such as advice on the general assessment status of an area, use of fishing gears, harvest control rules for fish stocks and other organisms and risk assessments of human activities such as petroleum exploration and fishing. Advice to the Ministry of Fisheries and Coastal Affaires in order to implement the prescriptions in the Oceans Resources Act regarding human activities in the Norwegian part of the Arctic Ocean should be given special attention by IMR.

At present the advisory function regarding the Arctic Ocean takes place within different research or advisory programs and projects without any overall co-ordination. In order to secure a more consistent and science based advisory process the present committee is of the opinion the advisory process of IMR should be more coordinated.

*The advices given from IMR should be organized as follows:*

- IMR should provide advice to all relevant management authorities; thus advice should be given within a wide range of issues.
- All advice given by IMR must be coordinated and approved by an appointed arctic Arctic advice director/committee to ensure both scientific quality and institutional coordination.
- Emphasis should be put on the start and finalization of the different advice processes. All requests forwarded to IMR should first be evaluated and clarified by the advice director before the assignment of formulating the advice is given to a relevant scientist or project. All advice on Arctic and polar issues should be approved and signed by the advice director. Care should be taken that theories or hypotheses on development in the Arctic Ocean put forward by individual scientists are not considered by the management authorities to be official advice from IMR.

# 5 Designing a long-term monitoring program

Due to the insufficient knowledge at present, a baseline study must be conducted before a long-term monitoring program can be developed. Below we outline the general aspects that have to be covered by the monitoring program.

## 5.1 Data series already sampled, analysed and available for IMR

*Hydrography*

Investigations of hydrography and currents in the Arctic Ocean are limited and sporadic, and mostly confined to the shelf slope towards the Barents Sea. In 2012, a new standard section (Polhavsnittet crossing the shelf-slope at 30$^{o}$E) was started. Hydrography and plankton in this section will be sampled annually (in August-September). As part of a joint Fram Centre project, 8 current meter moorings were deployed in the section in September 2012. Data from these moorings (in combination with numerical modelling) will increase the knowledge of the Atlantic inflow on the Arctic Ocean, and its impact on the ice cover and thus in turn on the ecosystem.

*Chemistry*

Most investigations on biogeochemistry have taken place on research vessels and there have been no collected effort to initiate a time series to investigate the biogeochemistry in the Arctic. Other oceans have time series stations which provide valuable information such as the anthropogenic $CO_2$ uptake Svalbard the oceans as well as changes in $CO_2$ chemistry (pH and $pCO_2$ trends). This is lacking in the Arctic Ocean which is a paradox since this is where we expect the largest changes in both climate and ocean acidification to effect ecosystems. In 2012, several projects at the Fram Centre, joined forces to establish time series sections and samples were taken and analysed for carbon and nutrient chemistry to study issues such as carbon export, ocean acidification and water masses, along the new Polhavsnittet. In summer 2011, IMR initiated collaboration with Norwegian Polar Institute to establish a time series across the Fram Strait at 78°30'N. This was continued in 2012 as part of the Ocean Acidification Flagship at the Fram Centre in collaboration with the "Sea Ice in the Arctic Ocean, technology and agreements Flagship". In addition to annual expeditions to Fram Strait automated water samplers at 5°W, 79°N were deployed to provide weekly sampling for inorganic nutrients, oxygen isotope tracers and carbonate system parameters. The data will make an important contribution to investigate the seasonal variability of the ocean acidification state and the influence of climate effects such as sea-ice melt water, Atlantic and Polar water.

*Seals*

Harp and hooded seals have been subjected to commercial hunting since the 1700s. Since the 1950s, IMR has been responsible for the monitoring and collection of data to assess status and harvest potential for the two species in the Greenland Sea (the West Ice, both species) and in the Barents Sea / White Sea (the East Ice, only harp seals). This has given a unique time series, now spanning between 50 and 60 years. The requirement for increased data quality has intensified during the most recent decades, and more systematic abundance estimation efforts began in the 1980s. To estimate seal population sizes, surveys are generally timed to coincide with those times when the maximum proportion of the population is visible for counting: the breeding and/or the moulting period. Harp and hooded seal surveys are allocated to the former. Total abundance of the seal populations are currently estimated by fitting a population model using age specific reproductive rates and catches to independent estimates of pup production. Although mark-recapture techniques have been used previously, the use of aerial photographically and/or visually based strip transect surveys over the whelping patches is currently regarded the best alternative to assess pup production. Current management of harp and hooded seals requires that data used in the models are updated every 5 years.

Data on seal diets and body condition are also available, from harp and hooded seals in the Greenland Sea from 1999-2010, and from harp seals in the Barents Sea from 1990-2011.

## 5.2 Monitoring

A long-term monitoring program for the Arctic Ocean should be established to observe which changes are taking place in the physical and chemical characteristics of the area as well as the effects these changes may have on the ecosystem. This program will have to reflect the seasonal fluctuation of sea ice in the area, since access will partly be limited to the summer/autumn period when sea ice coverage is at its minimum. An ice-going vessel will be able to enter the area also outside this period but activities like sampling of pelagic and benthic organisms will be limited. In connection with this monitoring program, modelling activity should be established, in order to put the data obtained into context. A data assimilation activity should also be considered to fill the gaps in the data acquired from the area, since both the cost of surveying and the limited access to the area will limit the amount of data.

It is necessary to develop a spatial monitoring program combining sections across the shelf-slope, regional coverage and more intensive sampling in key regions identified as suitable for early detection of changes.

Key tasks in the monitoring will include:

- Oceanography and habitat mapping
    - Hydrographic sections for chemical and physical oceanography spanning the border area between the Barents and Norwegian Seas and the Arctic Ocean. These should be observed at least once during the open-water period and perhaps also once or twice per year during the melting and freezing periods.
    - An area coverage with CTD profiles and water sampling and analsysis for carbon system (inorganic and organic carbon), inorganic nutrients, oxygen and isotopic tracers should be made during the ice-free period.
    - Ice extent during all seasons should be observed using satellite imagery
    - Oceanographic data can also be obtained from satellite based tags deployed on seals, in particular harp seals.

    - The seabed should be mapped using multi-beam echo sounders, side-scanning sonars, video monitoring etc.
- Sympagic community
    - Under-ice fauna (ice algae and zooplankton feeding on them) should be observed during surveys reaching the ice border as well as those going into fast ice.
    - Sympagic sea mammals and sea birds should be recorded during surveys reaching the ice border as well as those going into fast ice. Samples (in particular for diet and condition studies) should be obtained from the most numerous species, in particular harp seals.
- Pelagic community
    - Chlorophyll ***a*** should be regularly observed using satellite imagery, but also measured *in situ* during survey and transect work.
    - Primary production should be estimated using *in situ* $^{14}C$ uptake method (dawn to dusk) as well as fast repetition rate fluorometry (FRRF).
    - Phytoplankton and zooplankton should be sampled and observed using state-of-the-art sampling gears and observation platforms including Optical Plankton Counters (OPC/L-OPC's), Video Plankton Recorder (VRP) and video equipment attached to trawls ("Deep Vision"). For zooplankton it should be evaluated if their density and distribution could be measured using acoustic techniques and if towed integrated measurement platforms (MUST and MESSOR) could also be used in fully or partly ice-covered regions of the Arctic Ocean.
    - Pelagic fish should be sampled and observed using pelagic trawls, possibly with attached video equipment ("DeepVision"), and their density and distribution measured using acoustic techniques.
- Demersal community
    - Demersal fish should be sampled and observed using demersal trawls, possibly with attached video equipment ("DeepVision"), and their density and distribution measured using acoustic techniques.
    - Benthic organisms should be sampled and observed using various sampling gears designed for such sampling, including video monitoring and photography.

The frequency of surveys should be considered in light of the available funding, the available ocean-going and ice-going ships, and available scientists on the one hand, and the ideal or minimum amount of data needed for the purpose, on the other. Realized frequencies could vary from seasons to every second or third year, depending on survey purpose. It has already been suggested that the autumn Norwegian-Russian Barents Sea Ecosystem Survey (BESS) will be expanded to cover the areas north of the Barents Sea in the years to come, if these areas will be open during that period. In fact, this expansion has already started, since the 2012 BESS covered the shelf and slope areas north of Svalbard and Franz Josef Land (Figure 4). This will make up a good start for the Arctic Ocean monitoring program for two reasons: first, this continuation of an already established survey will secure that state-of-the-art equipment and methods will be used and second, that key processes on the borderline between the areas further south and the Arctic Ocean will be observed in the season when ice extension is at its minimum.

### 5.3 Modelling

Monitoring of the Arctic Ocean ecosystem should be complemented with numerical modelling. Part of the ongoing IMR modelling activities, like downscaling and general circulation modelling of the Arctic Ocean, are presently done in cooperation with other institutions like the Bjerknes Centre of Climate Dynamics and the Fram Centre, and this cooperation should be continued.

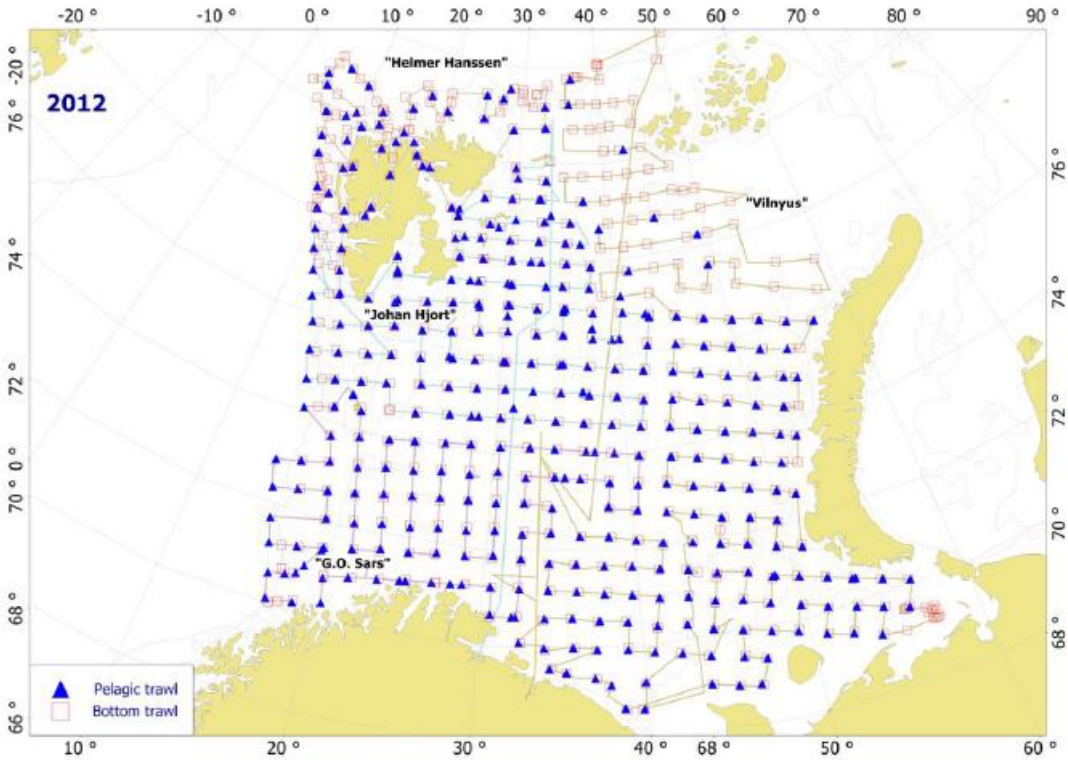


**Figure 4**. Survey coverage of the Barents Sea Ecosystem survey in 2012.

Key tasks in the modelling should include:

- Regional downscaling of global climate prediction models to reveal realistic predictions of the Arctic Ocean climate and circulation in the future
- General circulation models (for simulations of present and future time) to investigate changes in the Atlantic Water subduction and inflow, mixing along and across the slope, the water mass distributions and ice cover
- Biogeochemical modelling to investigate primary and secondary production, advection into the Arctic Ocean with the Atlantic inflow, cross-shelf exchange of zooplankton between the Arctic Ocean and the Barents Sea, and carbon transport to at the entrance to Arctic Ocean and into the deeper layers.
- Larvae-drift modelling to investigate drift of egg and larvae into the Arctic Ocean. Of particular interest is to use these models to evaluate spawning success if spawning is to occur in new areas. E.g., if spawning is to occur at Svalbard or Novaya Zemlya, will the spawning products drift into areas where they can survive, or will the products spawned at these new spawning grounds vanish/disappear?

# 6 International collaboration

There is a tremendous interest in the Arctic Ocean, and it is important that IMR collaborate both with international and national institutions when extending the activity northwards. Focus should be on the following collaborators and aspects:

- ICES. In a newly lounged press release (November, 2012), ICES states that Arctic research is a priority for ICES from the perspective of better understanding ecological processes and human impacts in this ecosystem. It is also stated that ICES seeks collaborative opportunities in Arctic, and that ICES is planning to take a leading role in the development of integrated surveys. Thus IMR should have a close cooperation with ICES in the development of ecosystem research, monitoring and management in the Arctic Ocean.
- Russia. Norway and Russia share the same fisheries resources and have a long-lasting well-functioning cooperation that must be continued also when focusing on the Arctic Ocean.
- IMR should be an active partner in international efforts to investigate and monitor the physical and chemical state (hydrography, pollution, ocean acidification) in the Arctic Ocean and should propose collaborative multi-disciplinary projects on monitoring the state.
- IMR should participate in relevant meeting and working groups to become visible also in a pan-Arctic framework. E.g., participation in Arctic Council working groups seems relevant.
- IMR should be present at Svalbard and contribute to research and collaboration with relevant partners already having research facilities in Svalbard. At the same time IMR should facilitate guest researchers onboard the scientific surveys conducted around Svalbard and into the Arctic Ocean.

# 7 Recommendations

Based on the evaluations thoroughly considered in the report the committee gives the following recommendations considering the IMR activity in the Arctic Ocean:

**A baseline study:**

- Planning of a joint IMR, University in Tromsø and Norwegian Polar Institute survey in the Arctic Ocean (using the new ice-going vessel) scheduled for autumn 2016 should commence in 2013.
- The joint IMR-PINRO ecosystem survey should be extended northwards to cover the ice-free water in the Arctic Ocean from 2014.

The baseline study should lead to:

**Scientific research**

- To estimate vital rates and parameters that are important for the functioning of the present Arctic Ocean ecosystem (using numerical modelling and process studies).
- To evaluate the impact of changes in productivity and whether any such changes might result in restructuring of the Arctic marine ecosystem.
- To investigate the interplay between the Arctic Ocean and the shallow shelves.
- Evaluate environmental risks of human activities.

**Advice**

- IMR should provide advice to all relevant management authorities; thus advice should be provided for a range of issues on the environment and biological resources.
- Major emphasis should be on the start and finalization of the various advice processes.
- All advice given by IMR must be coordinated and approved by an advice director/committee to ensure both scientific quality and institutional coordination.

**Monitoring**

- Prioritize regional monitoring of the biological resources and the ambient environment, incorporating seasonal variability.
- Identify key regions and establish relevant time series (old and new ones) suitable for early detection of changes in the Arctic Ocean ecosystem.
- New monitoring as identified by the baseline study.

# Appendix 1: Mandate

**Utvalg til å vurdere Havforskningsinstituttets økosystemaktivitet i Polhavet**

Fra Harald Loeng 20.08.2012

**Bakgrunn**

Klimaendringer og økende etterspørsel etter naturressurser gjør at den menneskelige aktiviteten i Arktis øker. Redusert isdekke og stigende vanntemperaturer kan føre til endringer i økosystemene, og det kan i fremtiden bli aktuelt å høste fra Polhavet.

Det finnes noe kunnskap om hvilke økosystemendringer som kan forventes i Arktis (for eksempel ACIA), men det er fremdeles store kunnskapshull knyttet til dette temaet. Kunnskap om raske endringer i de marine økosystemene, nye arter i Polhavet og påvirkningen fra/på økosystemet i Barentshavet er fremdeles mangelfull. Det er viktig at Havforskningsinstituttet allerede nå vurderer hvilken fremtidig økosystemforskning som er nødvendig.

Forvaltningen av levende marine ressurser og økosystemer i nord er kritisk avhengig av gode, vitenskapelige råd. Fordi det i fremtiden kan bli aktuelt å drive fiske i Polhavet er det viktig at Havforskningsinstituttet er nasjonalt førende i prosessen som har med forskning for forvaltning av levende marine ressurser/økosystemer.

**Utvalgets sammensetning:**

Randi Ingvaldsen (leder og oseanografi), Melissa Chierici (kjemi), Tor Knutsen (plankton), Harald Gjøsæter (lodde, polartorsk), Bjarte Bogstad (bunnfisk), Tore Haug (sjøpattedyr), Lis L. Jørgensen (bunndyr), Hein Rune Skjoldal (biodiversitet), Geir Huse (program Bestandsdynamikk), Knut Sunnanå (Barentshavsprogrammet), Ingolf Røttingen (Norskehavsprogrammet), Alf Håkon Hoel (Arktis og rådgivning)

**Mandat:**

1.Skissere mulige økosystemendringer i Polhavet i forbindelse med oppvarming.
2.Foreslå hvilken økosystemforskning Havforskningsinstituttet bør ha i Polhavet
3.Hvilken rådgivning bør Havforskningsinstituttet ha dersom det skal høstes fra Polhavet?
4.Skissere hvilke datainnsamling og modelleringsaktivitet som må til for å svare opp pkt.1 og 2.
5.Skissere kort hvordan Havforskningsinstituttet bør posisjonere seg i internasjonal sammenheng
6.Lage skisse for en SIP som kan sendes FKD

Utvalget lager utkast til en SIP innen 15. september 2012 og leverer sin endelige rapport til Ledergruppen innen 1. desember 2012.

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